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(71) Applicant: High Yield Technology
2400 Bayshore Frontage Road
Mountain View, CA 94043(US)

(72) Inventor: Borden, Peter
354 Tennessee Lane
Palo Alto, CA 94306(US)

(74) Representative: Noz, Franciscus Xaverius, Ir. et al
Algemeen Octrooibureau P.O. Box 645
NL-5600 AP Eindhoven(NL)

(54) Particle detector for wafer processing equipment and method of detecting a particle.

(57) A particle detector includes a laser, a beam shaping lens, and a pair of mirrors which reflect the shaped laser beam back and forth between the mirrors a selected number of times in order to create a sheet of light or light net between the mirrors. The path of the beam is terminated by a beam stop which contains a photodiode to monitor beam intensity and thereby system alignment. Light scattered by a particle falling through the sheet of light is gathered and transmitted to a photodiode. A peak detector provides a measure of the peak intensity of light scattered by such a particle to a microprocessor, which counts the number of particles falling through the light net in a selected time interval. The microprocessor also uses the peak intensity to estimate the size of the particle.

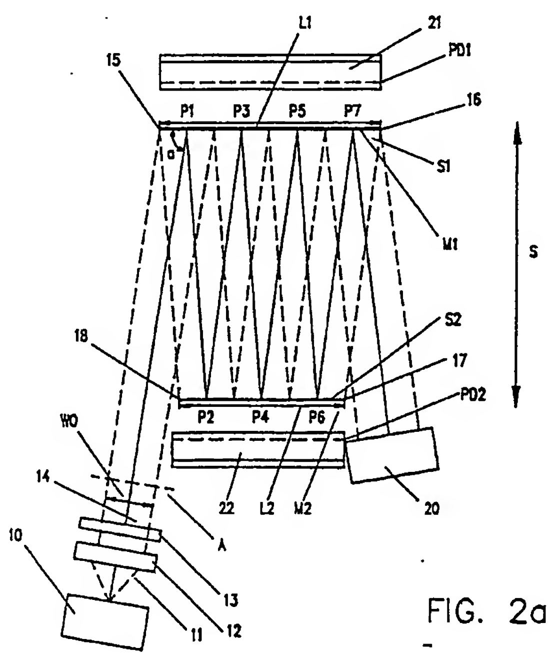

FIG. 2a

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PARTICLE DETECTOR FOR WAFER PROCESSING EQUIPMENT AND METHOD OF DETECTING A PARTICLE

FIELD OF THE INVENTION

This invention relates to a particle detector and in particular to a particle detector for monitoring airborne particles or particles in a vacuum, or in a fluid environment.

BACKGROUND

As wafer size increases and as device geometry becomes smaller, particulate detection and control becomes ever more important in semiconductor processing. Monitoring of particulate levels is important in processes which take place in an environment of air at atmospheric pressure, for example exposure of photoresist patterns, and for processes which take place in a vacuum chamber, for example deposition of metal films. Particulate contamination can be reduced for processes which take place in an environment of air at atmospheric pressure by the use of so called clean rooms which employ air filtration systems. Even with air filtration systems, however, processing equipment employs moving parts which generate particles and monitoring of particulate levels is therefore desirable for early detection of system breakdowns which produce excessive particulate levels.

One prior art method for detecting airborne particles is shown in Fig. 1. Sampled air (indicated by arrow 5 in Fig. 1) is drawn through narrow transparent tube 6 by a vacuum pump (not shown) attached to end 6a of cylindrical tube 6. Monochromatic light 1 from a laser (not shown) or white light from a lamp (not shown) is focused by lens 2 to form a focused beam 3 which passes through transparent tube 6 at a selected point along the tube. Light scattered from particles in sampled air 5 drawn through tube 6 which passes through beam 3 is detected by detector 7. Alternatively an opening (not shown) in tube 6 and an air sheath may be provided so that the focused beam passes through the opening in the tube. Detector 7 contains a photomultiplier and its construction is well known in the art. The scattering intensity is roughly proportional to particle size. Such systems commonly detect particles having a mean diameter in a range between 0.1 microns and 7.5 microns and in principle even smaller and larger particles can be detect d using the above system.

This prior art particle monitoring d vice has several drawbacks:

(1) It essentially samples air from a point, i.e. the point of the opening of the tube, and does not provide an adequate measure of particulate contamination over a wider spacial region. Often in a semiconductor processing environment, moving parts of various machinery may produce particles that will not be detected by sampling at a particular point. Thus prior art particle monitoring devices do not adequately monitor particles from multiple or distributed sources.

(2) The prior art monitoring system works in air but not in a vacuum chamber since it requires a flow of air to carry the particles.

(3) Particles may stick to the sides of tube 6 and then become airborne again at a later point in time thereby creating a delay effect.

(4) The physical end 6b of the tube must be placed physically close to the point being monitored which may interfere with other portions of the processing system.

SUMMARY OF THE INVENTION

A particle detector is provided which is suitable for detecting particles which are present in either air or in a vacuum. In one embodiment the detector includes a laser and beam shaping lenses which generate a beam whose height is small compared to its width. The beam is reflected back and forth between two mirrors a selected number of times in order to create a light "sheet" or "net" between the two mirrors. The path of the light is terminated by a "beam stop" which monitors the intensity of the beam thereby providing a measure of system alignment. Light scattered from a particle falling through the light net generated between the two mirrors is detected by one or more photodiodes. Signals generated by the photodiodes are amplified and processed by a peak detector. The peaks above a selected threshold value are counted by a microprocessor, which calculates particle flux density.

In one embodiment the beam is chopped and a lens is employed to focus the beam in order to compensate for beam divergence. Projecting members prevent dust from settling on the reflecting surfaces of the mirrors and also prevent light scattered by imperfections in the mirror surface from reaching the photodiodes. In a specific arrangement, the photocells are located so as to provide direct viewing of the light sheet between the two reflecting mirrors thereby enabling the making of a very compact sensor assembly. Since the reflecting mirrors are moved closer together in the com-

pact sensor assembly, a significant improvement in response to the sensed light beam is realized. In another arrangement which is useful for monitoring particles in high temperature environments, such as experienced with hot or corrosive gases or liquids, the sensor assembly includes a narrow, elongated pipe with attached glass windows to provide a small gap between the reflecting mirrors. The glass windows serve to protect the optical system from corrosion and heat. The housing for the sensor assembly is water-cooled to reduce thermal effects.

Two or more particle detectors of this invention may be ganged together to provide detection of particles falling through a large area, for example 8 inches by 8 inches.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows an airborne particle detector of the prior art;

Figure 2a shows a top view of the particle detector of the present invention;

Figure 2b shows the shape of the beam emerging from the beam expander shown in Figure 2a;

Figure 2c shows a partial side view of the particle detector shown in Figure 2a;

Figure 2d shows an alternate path for the light employed in the particle detector;

Figure 2e shows the path of the light scattered along 15° rays reflected by parabolic mirror 21 and focused on photodiode PD, shown in Figure 2a and Figure 2c;

Figure 3a shows the scattering cross section for a spherical particle into an angular region between θ and $\theta + 5°$;

Figure 3b shows the angle θ and $\theta + 5°$ employed in Figure 3a;

Figure 4 shows a block diagram of the circuitry used to process the signal received by photodiode PD_1;

Figure 5a shows a typical output signal of amplifier 34b shown in Figure 4;

Figure 5b shows the positive envelope of the signal shown in Figure 5a;

Figure 6 illustrates beam divergence as a function of path length;

Figure 7a shows integrated scatter cross section versus angular region;

Figure 7b shows the angular region between a cone having angle 10° and a cone having angle ϕ;

Figure 8 shows a lens arrangement for compensating for beam div rgence;

Figure 9 shows an alternate arrangement for compensating for beam divergence;

Figure 10 is a top view of a compact direct view sensor assembly, that is an alternative embodiment of this invention;

Figure 11 is a side view of the sensor assembly of Figure 10;

Figure 12 is an end view of the sensor assembly illusstrated in Figure 11;

Figure 13 is a top view of another alternative embodiment of the invention employing a compact sensor assembly including a pipe structure; and

Figure 14 is a side view of the sensor assembly of Figure 13.

DETAILED DESCRIPTION

Figure 2a shows a plan view (not to scale) and Figure2c shows a side view of one embodiment of the particle monitor of the present invention. Laser 10 is preferably a semiconductor laser, for example an AlGaAs laser operating at a wavelength of 820 nm. RCA laser No. C86000E and Hitachi laser No. HL8312E are suitable for this purpose. Other sources of light (not necessarily monochromatic) may also be employed with this invention. Beam 11 which emerges from the P-N junction of semiconductor laser 10 is shaped (collimated) by cylindrical beam shaping lenses 12 and 13 which are coupled to shape the beam in the horizontal and vertical planes. Beam 14 which emerges from lens 13 is shown in more detail in Figure 2b which shows a cross section of laser beam 14 along line A shown in Figure 2a. In one embodiment, beam 14 is modulated or chopped by circuitry shown schematically in Figure 5. Beam 14 has an initial height H_o and an initial width W_o determined by the width of the P-N junction (not shown) of semiconductor laser 10 and by shaping lens 12 and 13.

In one embodiment, the width of the P-N junction is approximately 40 microns and beam 14 as it emerges from shaping lens 13 has a width of 2.0 mm and a height of 0.4 mm. Laser 10 and beam shaping lenses 12 and 13 are positioned relative to planar dielectric mirrors M_1 and M_2 so that the dielectric surfaces S_1 and S_2 of mirrors M_1 and M_2 respectively are parallel to each other and perpendicular to the plane P through the center of beam 14 as shown in Figure 2b. The reflecting surfaces S_1 and S_2 of mirrors M_1 and M_2 have a length L_1 and L_2, respectively, and a height h as indicated by arrows L_1 and L_2 in Figure 2a and h in Figure 2c.

In Figure 2a the solid line emerging from laser 10 denotes the center of beam 14. Light at the c nter of beam 14 strikes surface S_1 at P_1 at an angle of incidenc $\alpha<90°$ and is r flected to point P_2 on surface S_2 and in general is reflected back

The focus of the parabola is 2 cm from the vertex V. The center of photodiode PD_1, which is 0.5 cm in width (vertical dimension in Figure 2e), is located at the origin (0,0) of the coordinate system and is 2.6 cm from vertex V. The distance between mirror M_1 and photodiode PD_1 is 0.2 cm and mirror M_1 is separated from mirror M_2 by 10 cm. Region 21a between parabolic mirror 21 and flat surface 21b contains glass having an index of refraction of 1.5 which refracts the rays of scattered light at 15° shown in Figure 2e toward the horizontal. (Surface 21b is the front surface of the glass.) The use of such a glass having an index of refraction greater than 1 increases the angle of acceptance, θ_a, which is the largest angle through which light can be scattered from a particle in beam 14 in front of mirror M1 and still be reflected to photodiode PD_1 via lens 21.

Table 1 in Figure 2e shows the acceptance angle θ_a (in degrees) as a function of x, where x is the distance of a particle in beam 14 in front of mirror M_1. As shown in Table 1, the minimum angle of acceptance for particles at least 1 cm in front of mirror M_1 is 15 degrees.

Figure 3a shows scatter cross-section for spherical particles as a function of angle and particle size for monochromatic light having a wavelength of 6328Å (from an HeNe laser) incident on the particle.

The abscissa in Figure 3a is labeled in degrees and each abscissa θ represents the solid region between the right circular cone having angle θ and the right circular cone having angle $\theta + 5°$ as shown in Figure 3b. The ordinates are measured in cm^2.

Curves A, B, C, D, E, F, G, H, and I are scatter cross-section curves for particles having a physical diameter of 0.2 µm, 0.3 µm, 0.4 µm, 0.5 µm, 1.0 µm, 1.5 µm, 2.0 µm, 2.5 µm, and 3.0 µm respectively. Due to interference effects, each particle has an apparent cross section which is different from its physical cross section. The scattering cross section shown in Figure 3a is the apparent cross section. An AlGaAs laser diode, as is used in the preferred embodiment, produces light having a wave length of 8200Å. The intensity of scattered light is somewhat less in this case, but the angular dependence is approximately the same as that shown in curves A through I in Figure 3a. Note that the most intense scatter is in the forward direction, for example curve A at approximately 25°. For this reason, the collector lens system shown in Figure 2c is used with the lenses located approximately perpendicular to the direction of travel of laser beam 14 in order to collect forward scatter. A system with collector lenses located on the sides of the laser net generated by laser beam 14 and generally parallel to the directions of travel of laser beam 14 would be operable but would be much less efficient.

In one embodiment, the light emitted from laser diode 10 is electronically chopped (pulsed) in a conventional way by connecting an AC current source 30 (shown schematically in Figure 4) to laser diode 10. The output signal of photocell 31 in beam stop 20 (shown in Figure 2a) is fed back to power source 30 of laser diode 10 in order to maintain a selected constant laser power output. The purpose of chopping the beam is to produce a particle detection system that operates in the presence of daylight or light from other nonmodulated light sources. This greatly improves signal-to-noise ratio since the detector circuit described below looks for signals at the chopping frequency rather than at DC. In one embodiment the frequency of the alternating current source is 3 megahertz and it is preferred to use frequency sufficiently high so that the laser beam has at least 10 on-cycles during the time it takes a particle to fall under the influence of gravity vertically through the light net generated by beam 14. For example, if it is assumed that a particle falls (under the influence of gravity) vertically downward through a beam having a thickness H = 0.03 cm at a velocity of 1500 cm/second (which corresponds to a particle falling from rest in a vacuum through a distance of approximately 1.15 meters) then ten cycles must occur in 1/50,000 seconds which corresponds to a frequency of 500 kHz. Since beam 14 is chopped, the scattered light that is received by photodiodes PD_1 and PD_2 as a particle falls through the light net generated by beam 14 is also chopped. The chopped scattered light sensed by photodiode PD_1 is amplified by amplifier 34a. Amplifier 34a is a low noise operational amplifier, for example, amplifier LT1037C made by Linear Technology. Alternately, amplifier 34a can be made of discrete components and a low noise FET, thereby providing an even better signal to noise ratio. It is preferable to mount amplifier 34a within 2cm of photodiode PD_1 in order to minimize noise pick-up in the connections. A second gain stage 34b is mounted in a separate housing indicated schematically by the dotted line in Figure 4. A typical output signal of amplifier 34b is shown (not to scale) by the solid line in Figure 5a. The dotted line connecting the positive peaks of the solid line in Figure 5a is the "positive envelope" of the signal. The output signal of amplifier 34b is sent to mixer 35 which may be, for example, part no. XR-2208, an analog multiplier made by Exar. Mixer 35 also receives the 3 megahertz signal from alternating current source 30. The output of mixer 35 (shown in Figure 5b) is the positive envelope of the output signal of amplifier 34b. The

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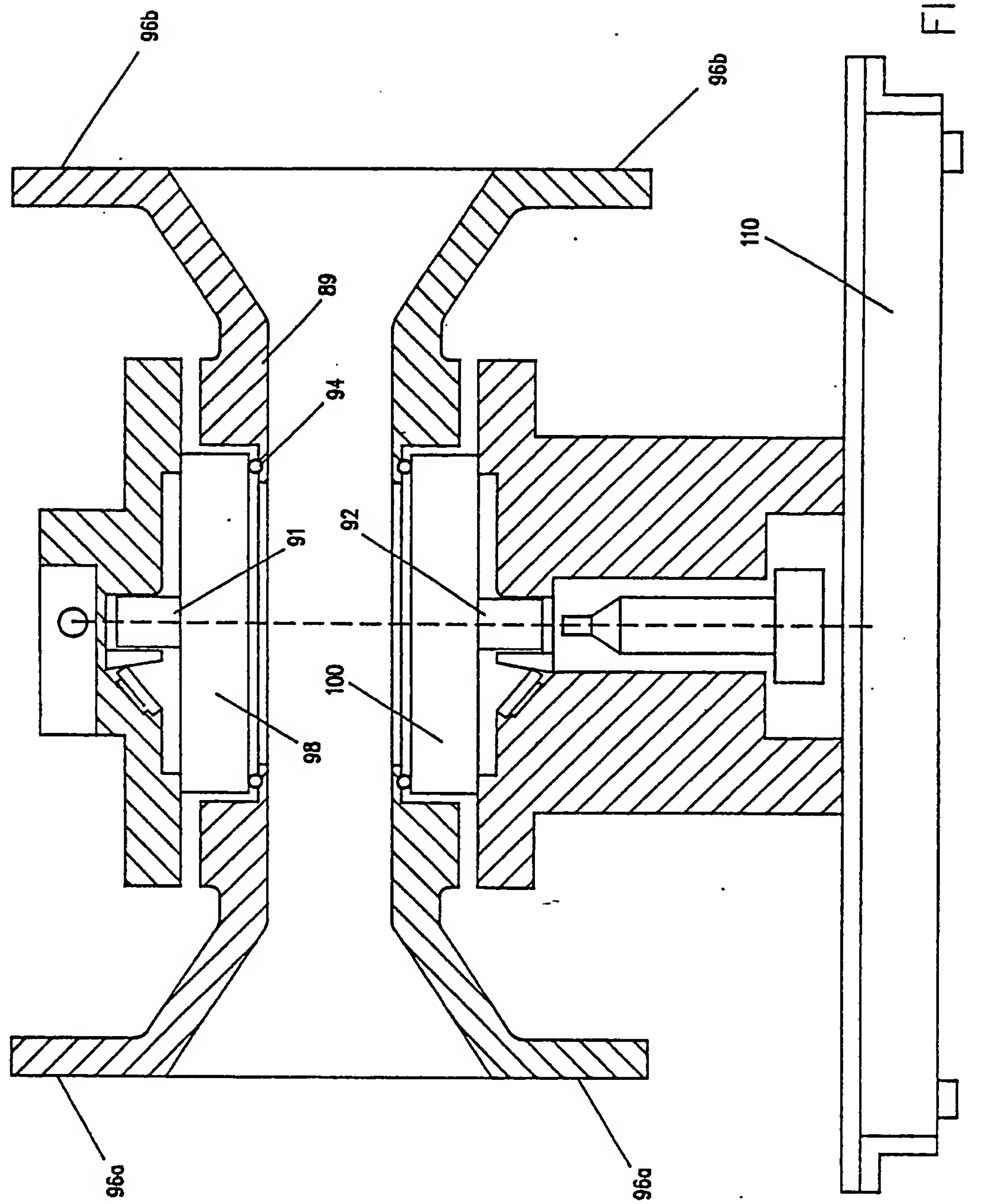


FIG. 14

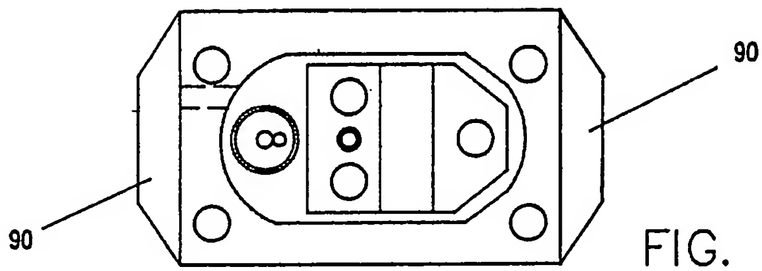


FIG. 12

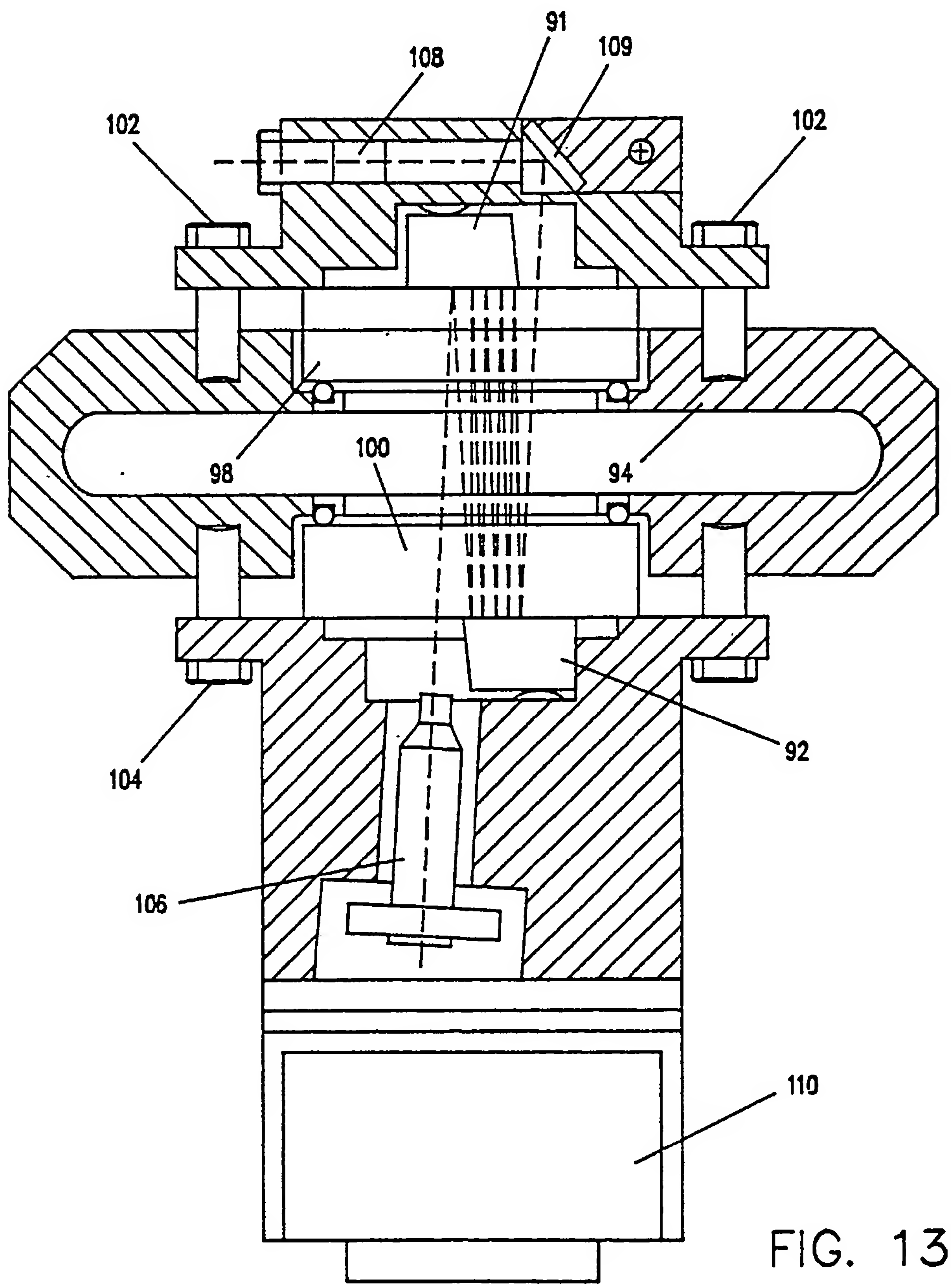


FIG. 13

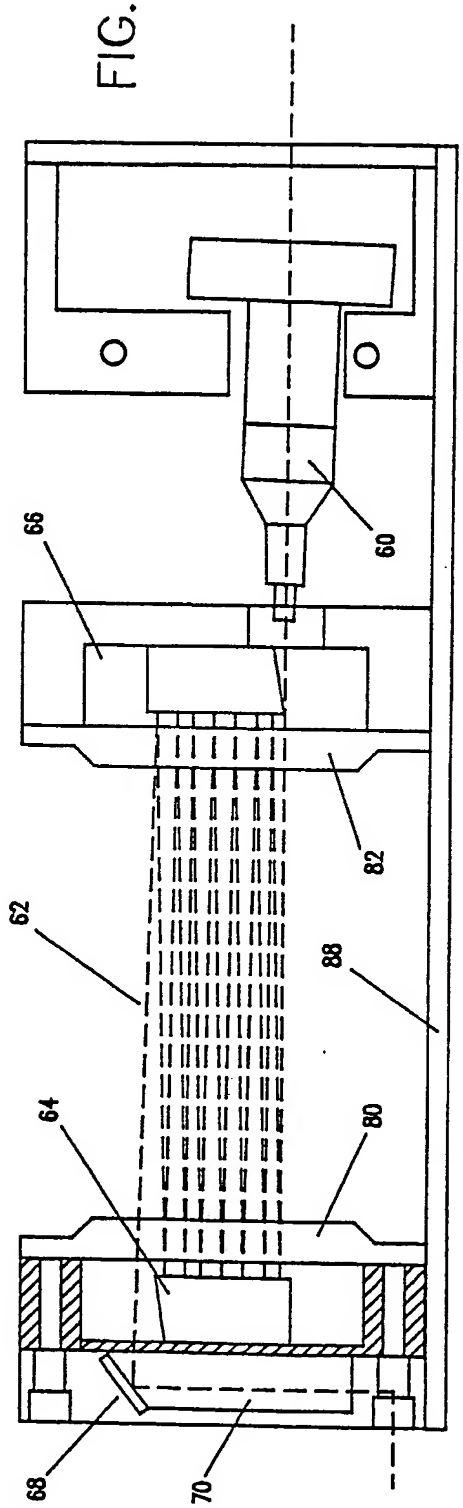


FIG. 10

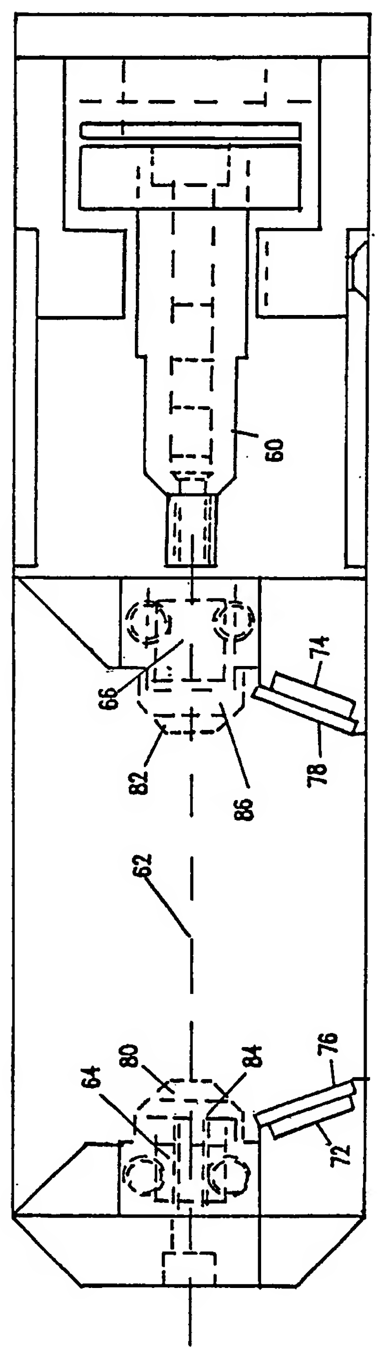


FIG. 11

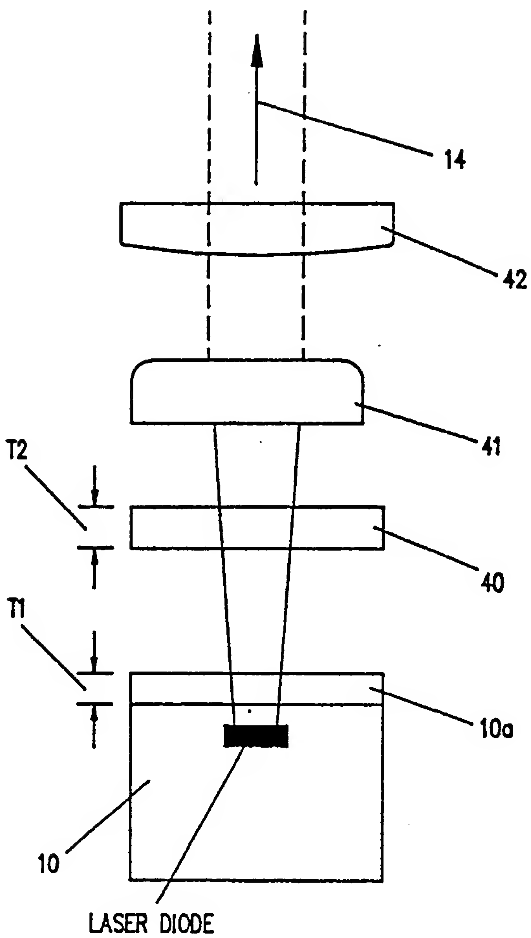

14
42
41
T2
40
T1
10a
10
LASER DIODE

FIG. 8

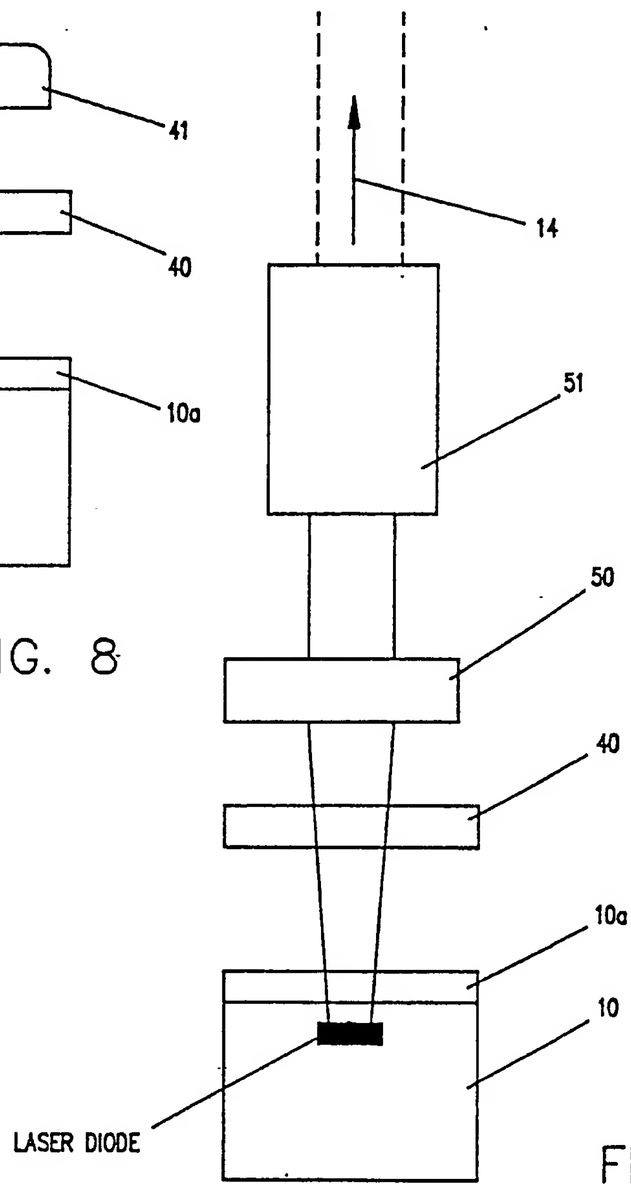

14
51
50
40
10a
10
LASER DIODE

FIG. 9

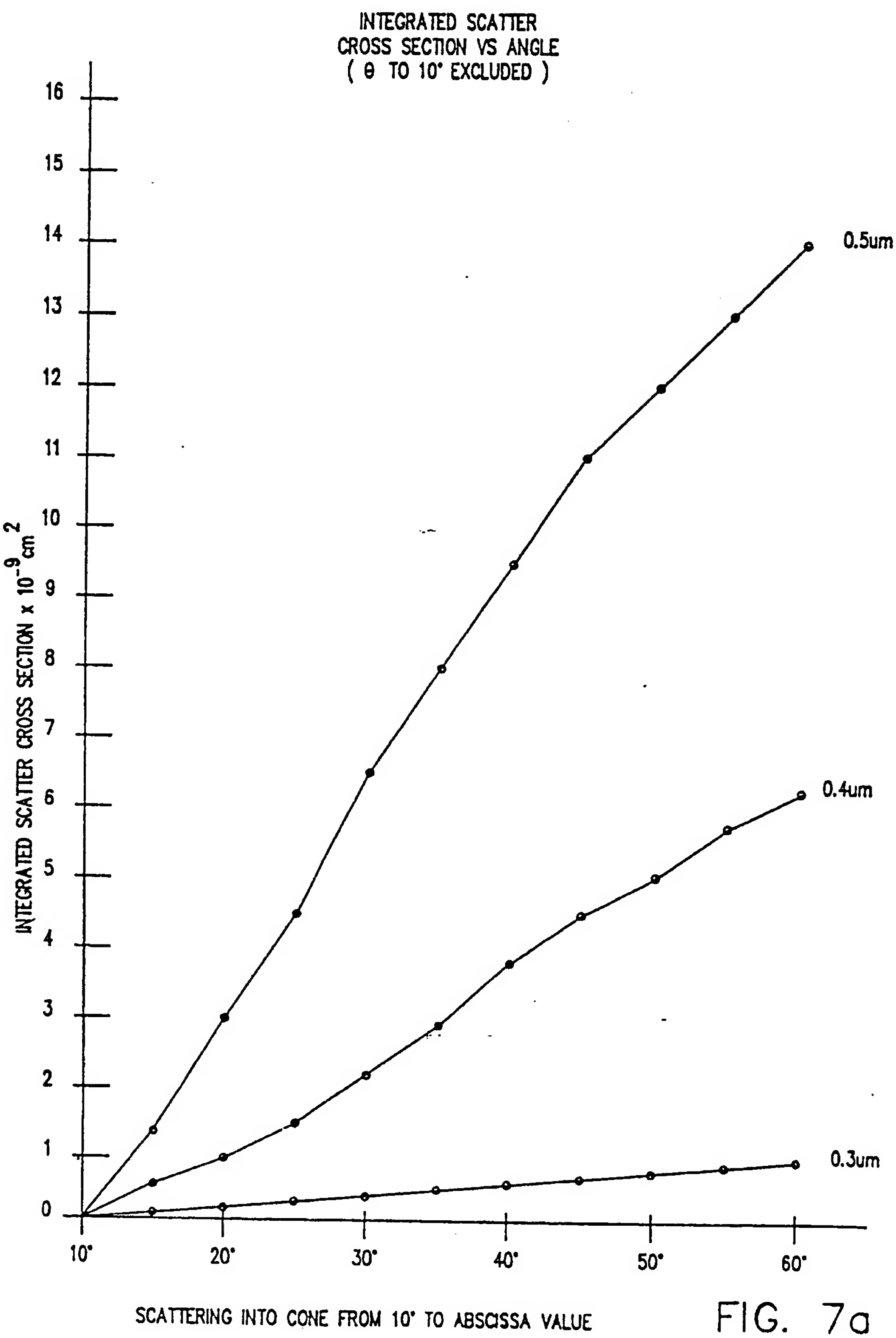

INTEGRATED SCATTER
CROSS SECTION VS ANGLE
(θ TO 10° EXCLUDED)
INTEGRATED SCATTER CROSS SECTION x 10⁻⁹cm²
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
0.5um
0.4um
0.3um
10°
20°
30°
40°
50°
60°
SCATTERING INTO CONE FROM 10° TO ABSCISSA VALUE

FIG. 7a

Neu eingereicht / Newly filed
Nouvellement déposé

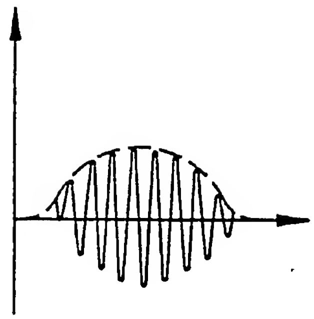


FIG. 5a

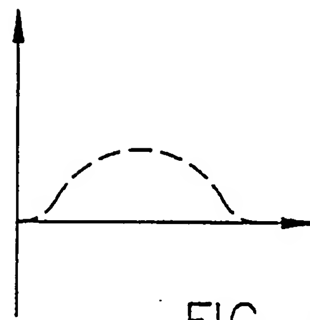


FIG. 5b

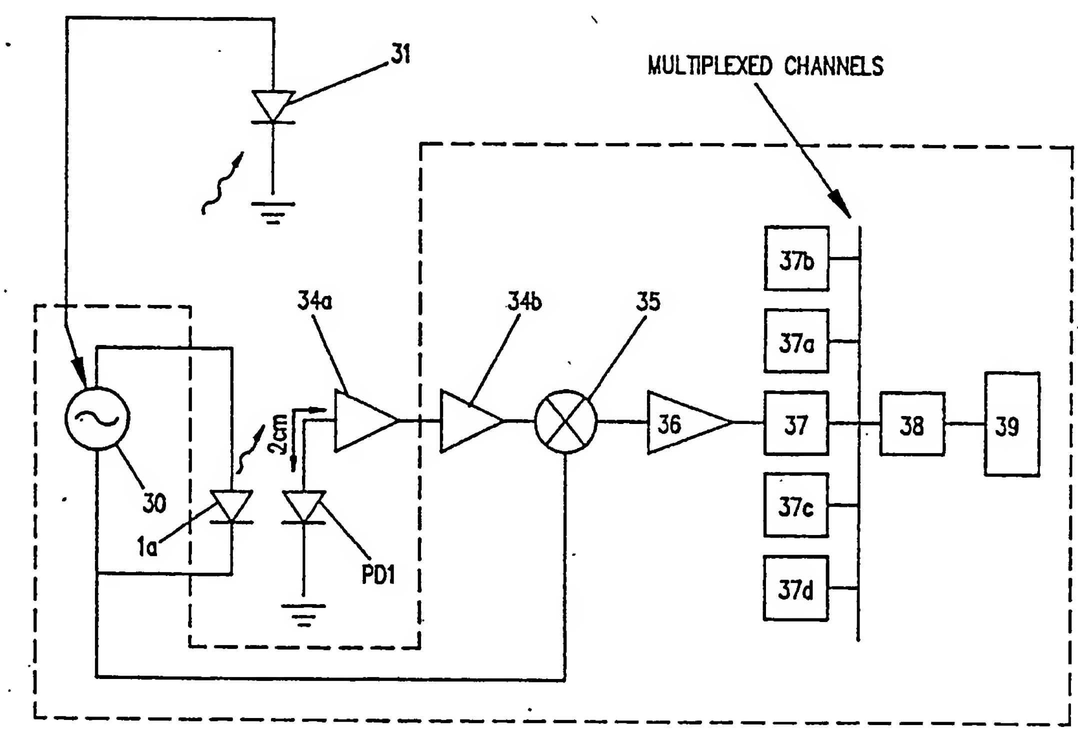


FIG. 4

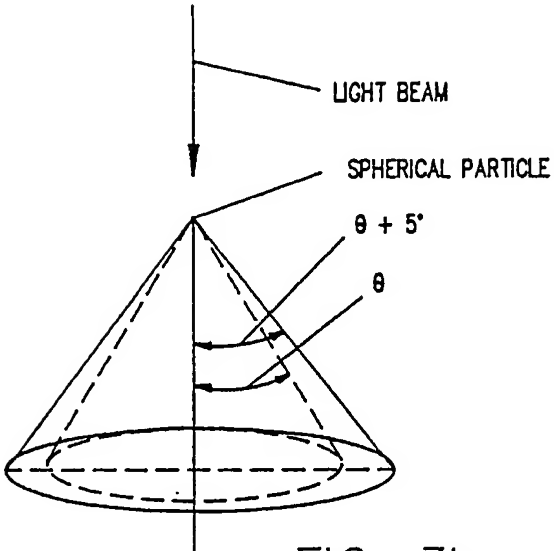


FIG. 3b

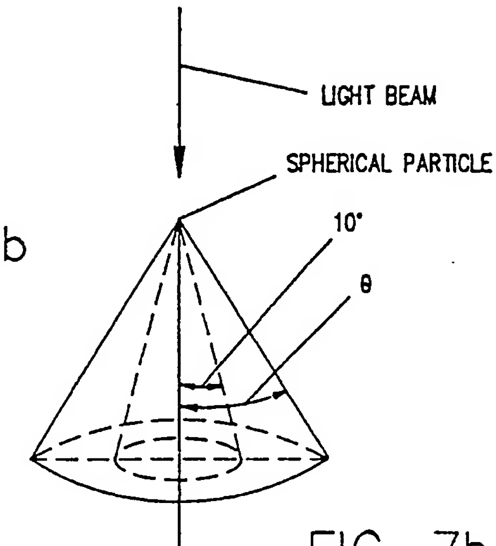


FIG. 7b

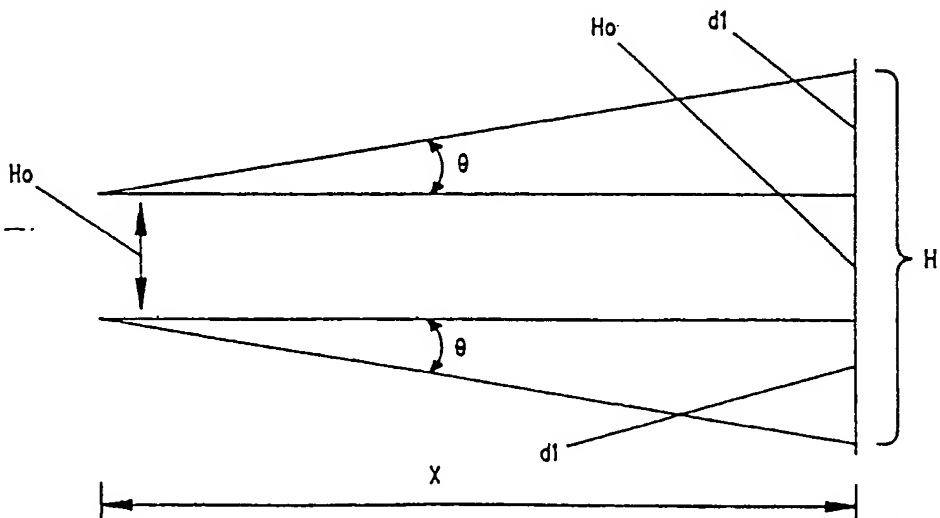


FIG. 6

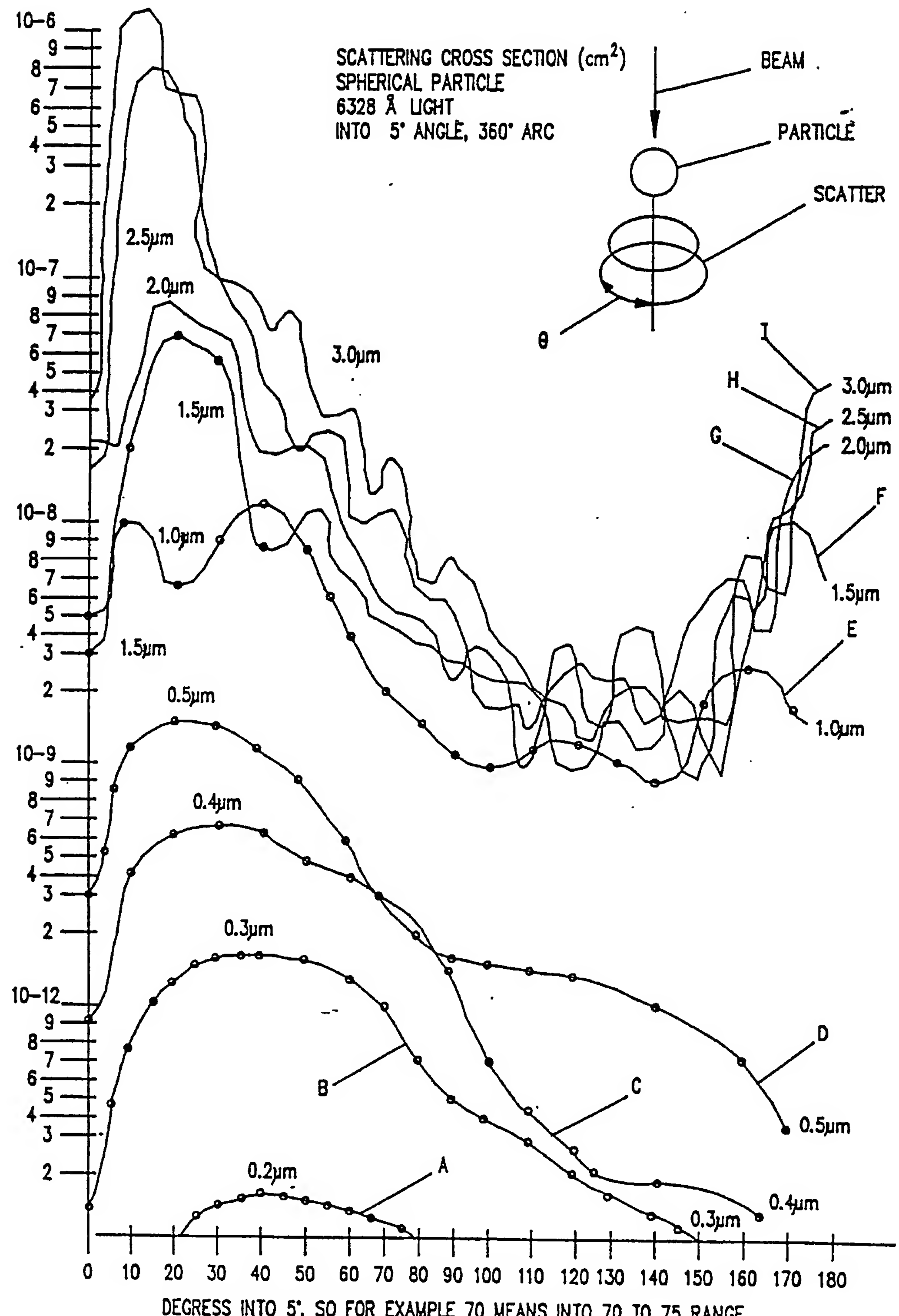

SCATTERING CROSS SECTION (cm2)
SPHERICAL PARTICLE
6328 Å LIGHT
INTO 5° ANGLE, 360° ARC
BEAM
PARTICLE
SCATTER
θ
10-6
10-7
10-8
10-9
10-12
2.5µm
2.0µm
1.5µm
3.0µm
1.0µm
0.5µm
0.4µm
0.3µm
0.2µm
A
B
C
D
E
F
G
H
I
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
DEGRESS INTO 5°, SO FOR EXAMPLE 70 MEANS INTO 70 TO 75 RANGE

FIG. 3

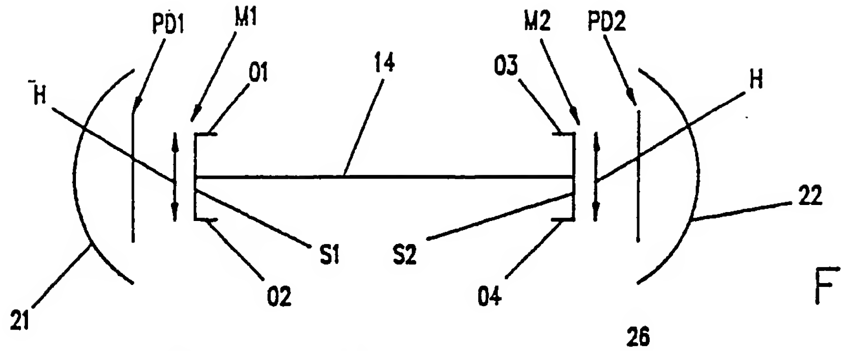


FIG. 2c

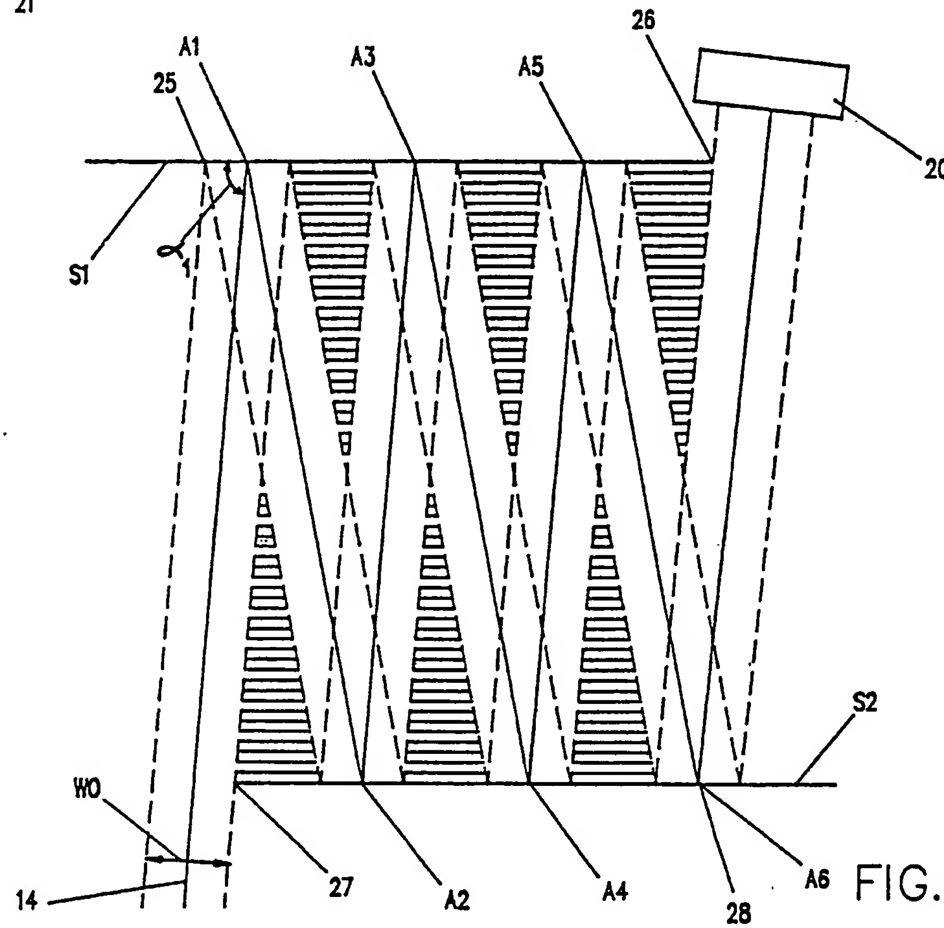


FIG. 2d

GLASS FILLED PARABOLA, FLAT FRONT (cm)

TABLE 1

X (cm) =	1	2	3	4	5	6	7	8	9	10
θ_α (deg.) =	15	18	20	20	20	20	19	18	17	17

15° RAYS

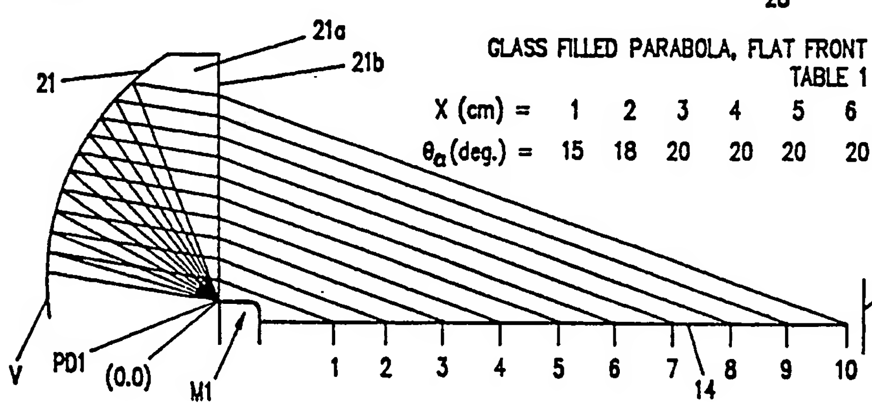
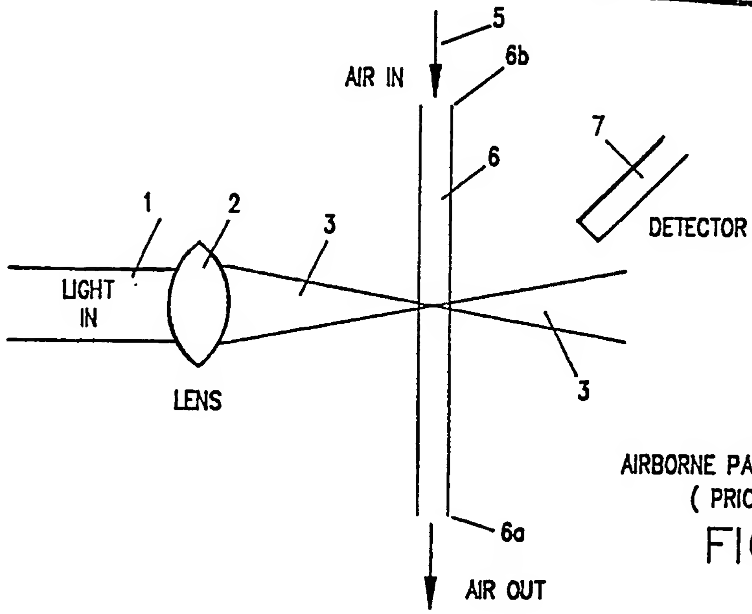


FIG. 2e



AIRBORNE PARTICLE DETECTOR
(PRIOR ART)

FIG. 1

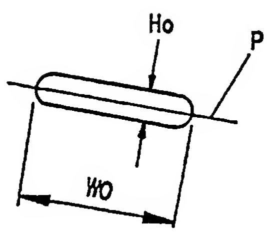


FIG. 2b

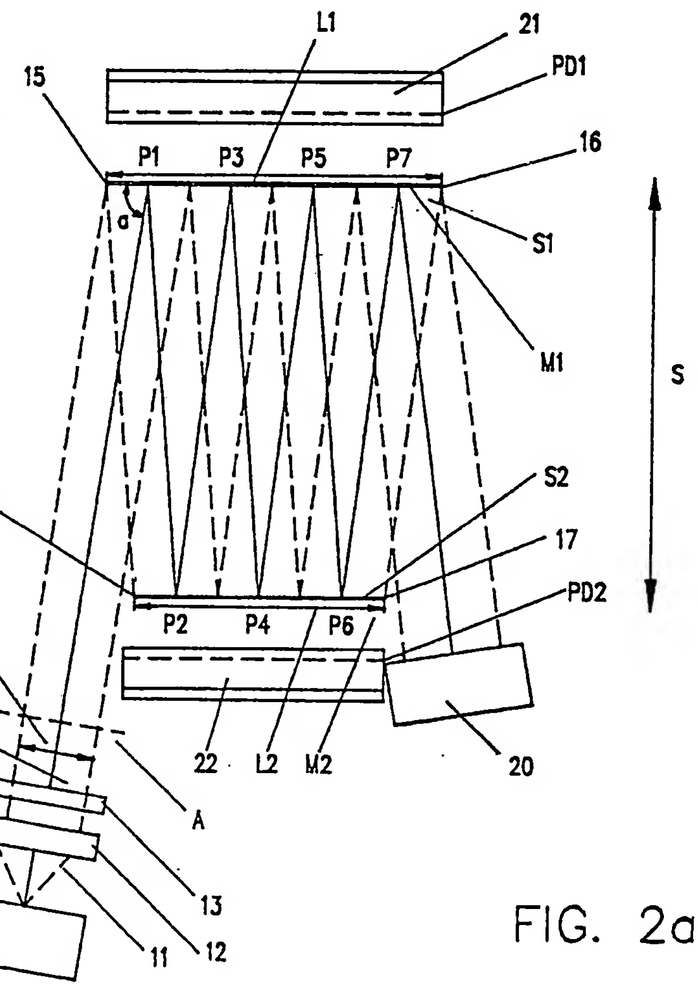


FIG. 2a

5. A particle detector as in Claim 1 wherein said means for generating a beam of light comprises a laser.

6. A particle detector as in Claim 1 wherein said first means for reflecting said beam of light and said second means for reflecting said beam of light each comprises a mirror having a planar surface.

7. A particle detector as in Claim 1 wherein said first means for reflecting said beam of light and said second means for reflecting said beam of light each comprises a mirror curved to reduce the divergence of said beam of light.

8. A particle detector as in Claim 1 wherein said means for generating a beam of light includes a lens having a focal length selected to compensate for beam divergence positioned between a source of said beam of light and said first means for reflecting.

9. A particle detector as in Claim 6 further comprising at least one member extending outward from one of said mirrors to prevent dust from settling on said surface of said one of said mirrors.

10. A particle detector as in Claim 6 further comprising at least one opaque member extending outward from one of said mirrors to prevent light scattered from imperfections in said surface of said one of said mirrors from being detected by said means for detecting.

11. A particle detector as in Claim 1 wherein said means for generating a beam of light comprises one or more lenses which produce a beam of light having a height less than its width.

12. A particle detector as in Claim 5 further including means for chopping said light beam.

13. A particle detector as in Claim 1 wherein said means for detecting comprises an optical element for gathering said light scattered by a particle and for reflecting said light scattered by a particle to a means for sensing said light scattered by a particle.

14. A particle detector as in Claim 13 further comprising a material having an index of refraction greater than 1 placed between said optical element and said means for sensing in order to increase the acceptance angle of said means for detecting.

15. A particle detector as in Claim 1 wherein said means for detecting scattered light comprises a collecting mirror and a photodiode, said collecting mirror focusing said scattered light on said photodiode.

16. A particle detector as in Claim 15 wherein said means for detecting further includes means for sensing a representative of the peak amplitude of a light signal received by said photodiode.

17. A particle detector as in Claim 16 wherein said means for detecting furth r includes an analog-to-digital converter and a microprocessor, said analog-to-digital converter providing said microprocessor with the digital representation of said representative of said peak amplitude of said light signal received by said photodiode.

18. A particle detector as in Claim 1 wherein said means for generating a beam of light comprises a gradient index lens.

19. A method of detecting a particle comprising:

generating a beam of light;

reflecting said beam of light from a first means for reflecting to a second means for reflecting and from said second means for reflecting to said first means for reflecting a total of N times, where N is a preselected positive integer greater than or equal of 2, and wherein said beam is initially incident on said first means for reflecting at an angle $\neq$ 90°; and

detecting light scattered by said particle passing through said light beam.

20. The method of Claim 19 further including terminating said beam after said beam has been reflected said N times.

21. A particle detector as in Claim 1, including a pipe section having a narrow cavity extending substantially transversely to said beam of light.

22. A particle detector as in Claim 21, including window means disposed adjacent to said pipe section and between said first reflecting means and said second reflecting means.

23. A particle detector as in Claim 21, wherein said light detecting means are positioned closely adjacent to said reflecting means.

24. A particle detector as in Claim 21, wherein said pipe section comprises flanged portions for coupling to external pipes so that fluids or gases can be passed through said narrow cavity.

first mirror 64 so that a light sheet or light net is produced in the narrow gap between the mirrors. The reflected beam passes over the first mirror 64 to impinge on a photodiode 68. The photodiode indicates the int nsity of the light beam that is received to ensure that the laser beam and the optical system of the sensor assembly are operating properly. The beam is reflected from the photodiode into a beam stop cavity 70 which prevents stray light from returning to the optical system, and provides a safety feature.

As illustrated in Figure 11, photocells 72 and 74 are positioned close to the mirrors 64 and 66 to detect the traversal of particles through the light sheet. The photocells generate signals representative of the incidence of particles passing in the gap between the mirrors. The signals are amplified, peak detected and processed by a microprocessor that computes the particle flux density, as described previously. A visual display is obtained by means of a display monitor that is coupled to the microprocessor. Glass filters 74 and 76 are provided with the photocells to block spurious light of different wavelengths than that of the laser beam. The mirrors have front pieces 80 and 82 which are made with dielectric stacks, formed of a substrate with a MAX-R (trademark of Melles Griot) coating that passes a wavelength of about 780 nanometers. The front pieces are attached to cover glasses 84 and 86 that are seated over the faces of the respective mirrors.

The sensor assembly is positioned in a frame 88, and support brackets 90, one being illustrated in Figure 12, enclose the ends of the frame to form a housing or enclosure for the sensor assembly.

An alternative embodiment of a sensor assembly is depicted in Figures 13 and 14. The sensor assembly, which is useful for particle detection of hot or corrosive gasses or fluids, is made with a pipe section 89 that is disposed in a substantially transverse direction between two reflecting mirrors 91 and 92. The pipe section 89 has a narrow central portion 94 and flared flange portions 96a, 96b which enable coupling the pipe section to standard diameter pipes through which the gas or fluid under detection is passed. Glass windows 98 and 100 are provided between the mirrors and the central cavity of the pipe section. The glass windows protect the optical system from corrosion and heat. The windows are made of a heat resistant, low temperature coefficient glass, such as fused silica. The glass is polished flat on the front and back surfaces. The mirrors are assembled to the windows, which ar mounted onto the pipe using fluorocarbon O-rings that are able to withstand temperatures up to 200°C. The mirrors are aligned by tightening two sets of three bolts 102 and 104 that clamp the windows to the pipe, while the O-rings provide the desired play.

When operating in high temperatur environments, the housing for the laser 106 and the beam stop structure 108, which includes the photodiode 109, are cooled by circulating cooling fluid or water through channels or pipes positioned in the housing. As previously described, a preamplifier 110 is provided to amplify the intensity of the laser beam.

With the small gap between the mirrors, as embodied in the alternative implementations of Figs. 10-14, a compact structure that provides improved signal resolution is made possible. The compact structures are made with a reduced number of parts and are less costly to manufacture.

The scope of the invention is not limited to the specific arrangements, materials and parameters disclosed herein. For example, more than two mirrors may be used to generate the light net, and the optical system may be modified to provide a desired path for the light beam. Also, the pipe section described with reference to Figs. 13 and 14 may be cylindrical, a rectangular channel, or any configuration affording the compact narrow gap between the reflecting mirrors.

Claims

1. A particle detector comprising:
means for generating a beam of light;
first means for reflecting said beam of light;
second means for reflecting said beam of light, said means for generating, said first means, and said second means being positioned relative to one another so that said beam of light generated by said means for generating is reflected from said first means to said second means and from said second means to said first means, a total of N times where N is a preselected positive integer ≥2, and wherein said beam is initially incident on said first means for reflecting at an angle not equal to 90°; and
means for detecting light scattered by a particle passing through said light beam.

2. A particle detector as in Claim 1 further comprising a beam stop for terminating said beam after said beam has been reflected said N times.

3. A particle detector as in Claim 2 wherein said beam stop includes means for sensing the intensity of light incident on said beam stop.

4. A particle detector as in Claim 3 wherein said beam stop further includes means for emitting a signal when the intensity of light incident on said beam stop falls below a preselected value.

The minimum detectable cross section of a particle is found by equating the power received by the detector to the noise power and solving for σ, the particle scattering cross section, which yi lds: $\sigma_{min} = N\sqrt{B}/\eta P(x) = N\sqrt{B}\ H_oW_o(1+\lambda x/\pi H_o^2)(1+\lambda x/\pi W_o^2)/\eta P_oRn$. It is desirable to maximize σ_{min} as a function of H_o. The optimal value of H_o is given by solving $\delta\sigma_{min}/\delta H_o = 0$ which yields

$$H_{O,\ optimal} = \sqrt{\lambda x/\pi}.$$

For example, for a wavelength of 820 nm - (AlGaAs laser) and a propagation distance of 50 cm $H_{o,\ optimal}$ = 0.036 cm. For values of H_o = 0.036 cm, W_o = 0.1 cm, B = 200 kHz, N = 5 x 10^{-13} watts/$H_z^{1/2}$, η = 0.5, P_o = 10 milliwatts, λ = 820 nm, σ_{min} = 3.7 10^{-10} cm². For this σ_{min} a 30-degree detector can easily detect a 0.3 micron-diameter particle. A detector comprising a collector lens 21 and a photodiode PD_1 is a thirty degree detector if the photodiode receives rays making an angle up to thirty degrees with the plane of the light net generated by beam 14. Figure 7 shows the integrated scatter cross section versus angle - (0° to 10° excluded) for curves, B, C, and D of Figure 3a. The abscissa θ (in degrees) in Figure 7a represents the region between the right circular cone having an angle of 10° (with the vertical) and the right circular cone having an angle of θ as shown in Figure 7b. The power, P_θ, of light scattered into this region is given by $P_\theta = I_o\ \sigma_\theta$ where I_o is the incident power/unit area and σ_θ is the integrated scatter cross section corresponding to θ - (Figure 7a).

As the above analysis shows, the power density decreases with the propagation distance of beam 14 due to divergence.

Beam divergence can be compensated for by, instead of collimating the beam using lenses 12 and 13 as explained above, bringing the beam to a focus that exactly compensates for the divergence angle θ shown in figure 6. This is a technique that is well known in the art, and is discussed, for example, in Melles Griot Optics Guide 3, page 349, 1985. Figure 8 shows in more detail one preferred embodiment for compensating for this divergence. Laser diode 10 is typically packaged so that light emerging from the p/n junction of laser 10 passes through glass 10a. The thickness T_1 of glass 10a affects (by refraction) the dimensions of the beam which emerges from glass 10a and may vary from manufacturer to manufacturer. The focusing qualities of lenses 41 and 42 are sel cted based on a beam which has passed through a selected thickness T of glass greater than the varying thicknesses for plate 10a typically employed by different manufacturers. Thus, by inserting glass plate 40 having thickness T_2 where T_2 is selected so that $T_1 + T_2 = T$, the remainder of the optical system may remain unchanged when different laser diodes employing different glass thickness T_1 are used from time to time.

The beam which emerges from glass plate 40 passes through cylindrical lens 41 which focuses the beam in the vertical dimension indicated by the arrow Ho in Figure 2b. The radius of curvature of lens 40 is selected to exactly compensate for the vertical beam divergence angle θ shown in Figure 6. The beam emerging from cylindrical lens 41 then passes through cylindrical lens 42 which has a radius of curvature selected to exactly compensate for horizontal beam divergence (divergence in the width of the beam). Beam 14 emerging from lens 42 thus maintains a constant thickness and a constant width as it propagates between mirrors M_1 and M_2.

Alternatively, divergence in the thickness H of beam 14 can be corrected by slightly curving the mirror surfaces S_1 and S_2. The use of cylindrical lenses 41 and 42 described above is preferable to this second method since curved mirrors are expensive and difficult to implement.

A third method of collimation and divergence correction is to use a gradient index lens. Gradient index lenses are available from Melles Griot in the 06LGT product line in consumer specified length. A gradient index lens is a glass rod with an index of refraction that varies with diameter. A focusing action results as light propagates through the rod. The focal length of the gradient index lens is determined by the length of the glass rod. Figure 9 shows one embodiment of the optical means used to compensate for beam divergence employing a gradient index lens. The elements in Figure 9 that are the same as in Figure 8 bear the same numerical labels. In Figure 9, the beam emerging from flat glass plate 40 is received by cylindrical lens 50 selected so that the beam emerging from lens 50 has a desired ratio of height to width. The beam from lens 50 is received by gradient index lens 51 which collimates the beam along the horizontal - (width) axis and compensates for beam divergence angle θ (Figure 6) along the vertical thickness axis, so that the light net generated by beam 14 has constant thickness.

With reference to Figures 10, 11, 12a, and 12b, a compact direct view sensor is illustrated. The direct view sensor assembly includes a light source 60, such as a laser cartridge, having lenses that provide a collimated laser beam 62. The beam is directed to a first reflecting mirror 64 at an angle of about 15° relative to the planar face of the mirror 64. The beam is reflected to a second mirror 66 that has a face substantially parallel to that of the